

CHEMISTRY

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Forty-ninth
Year

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* Papers from International Conference on the
Peaceful Uses of Atomic Energy.

Editorial:

What Difference Will It Make?
Inside Front Cover

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What Difference Will It Make?

Now that use of atomic energy for industrial purposes appears to be right around the corner, what impact on our daily lives is this new energy source likely to make? Is a hamburger cooked by "atomic energy" any different from one cooked over any other source of heat? If an electronic counting tube is fired by a radioactive isotope, is this something new in the world of finance?

Up to now, such demonstrations have been merely "stunts". Although some electric current has been fed from atomic reactors into power lines, the amount has not been a drop in the bucket compared to the amount these same reactors have drawn over the same wires since the beginning of the industrial atomic age, a scant ten years ago. And it is the same old electricity with which we have become very familiar.

For somewhat less than 150 years electricity has been recognized as a manageable source of power. It is generated for practical use in two ways, by transformation of mechanical energy or from chemical energy, as in batteries. Atomic energy does not yet substitute for either of these, except on the microwatt scale. In the big industrial atomic reactors nuclear fuel merely substitutes for coal or oil to create heat to run the steam turbines.

This is a crude and primitive way to use the energy stored in atomic nuclei. More direct use so far is experimental and tentative.

Meantime many new problems of living in a world of increasing radioactivity must be met. Long-lived radioactive products which must be safely disposed of for the present, must ultimately be used, for their energy is too valuable to be wasted by a power-hungry world. Hazards of radiation are new and insidious, giving rise to biological mutants which may make life better, or perhaps disastrously worse. Some of these new problems were discussed in Geneva at the Atoms For Peace Conference, and appear in this issue of CHEMISTRY.

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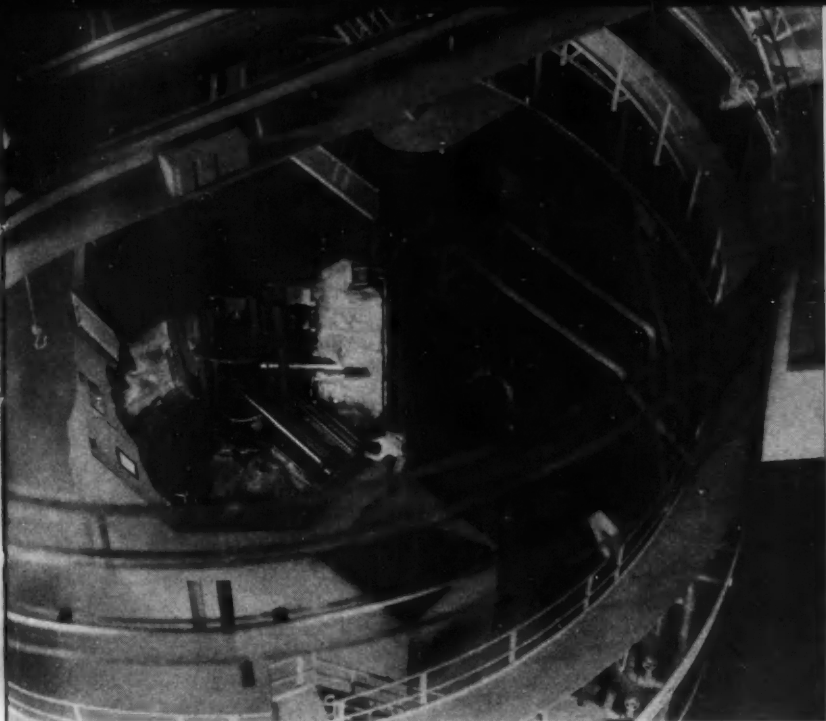
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► WHERE atomic energy is born is shown in this cut-away model from Argonne National Laboratory, exhibited at Geneva.

Isotopes in Industry

by S. E. EATON, Arthur D. Little, Inc.

► RADIOACTIVE isotopes are proving extremely potent as research tools for accelerating industrial progress. Developed as by-products of a military program, they are now creating new knowledge and understanding—of nature and of industrial processes and pro-

ducts—that will have positive and permanent value to mankind. The purpose of this paper is to discuss the unique and powerful features of radioisotopes which have been found particularly useful for industrial research, and to set forth some typical problems which they

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are solving in the United States of America.

You already know what radioisotopes are—atoms that give off radiation. They are what remains of the uranium atom after it has split; but they can also be made to order by irradiating ordinary atoms in nuclear reactors or particle accelerators. The radioactivity from massive quantities of radioisotopes can be used to promote chemical reactions, to preserve foods, or to measure or control the thickness of products during manufacture; but such uses are a subject in themselves outside the field of industrial research, and will not be covered in this discussion.

Radioisotopes are also proving tremendously important to agriculture researchers, nuclear physicists, and medical people; but what I would like to talk to you about today is the importance of radioisotopes to us industrialists and our research problems. Whether radioisotopes are going to be a necessary tool in the average company's research tool kit remains to be seen, but for those companies who value a microscope or chemical analysis or physical measurements, radioisotopes are certainly too powerful to be ignored.

Now just why are they so powerful? Why are they the only means of solving some problems?

Let us put down four principal points:

1. They are easy to detect.
2. They provide a small, inexpensive, portable source of radiation.
3. They can be measured in minute quantities with high sensitivity.
4. They are specific and can be traced in the presence of other chemically identical atoms. Except for some minor differences in the low-atomic-weight elements, radioactive isotopes are identical in chemical behavior to non-radioactive atoms of the same element. Thus specific batches of tagged or radioactive atoms from one source can be differentiated in the presence of other chemically identical atoms from a different source. Radioactivity is unaffected by temperature, pressure, or chemical composition.

There are other advantages, but I think these cover the principal points. Now what are these advantages good for in industrial research? The fact that radioisotopes are easy to measure can simplify identification of the constituents of a sample by activation analysis. Irradiation in a reactor or accelerator can make the sample radioactive in a manner characteristic of its constituents. A knowledge of these characteristics then allows interpretation of the sample's radioactivity in terms of its composition. The method is

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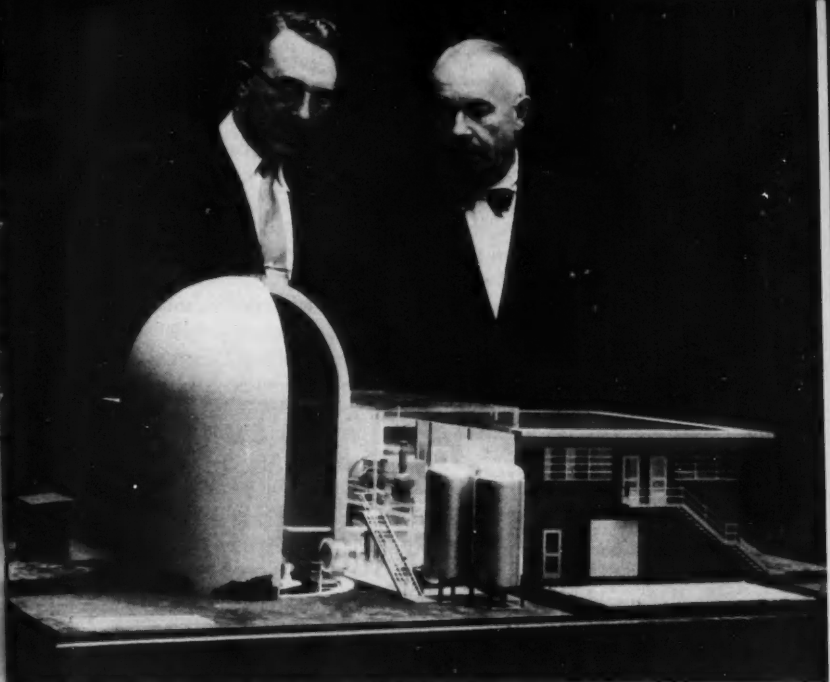
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► *MODEL of the Experimental Boiling Water Reactor, Argonne National Laboratory, built to show the construction of the real atomic steam generator.*

proving of particular value where a non-destructive test for traces of metallic impurities is desired.

Ease of measurement also makes it simpler to determine optimum mixing time for such materials as paint, ink, plastic products, powders for powder metallurgy, and the like. One of the components can be tagged with radioactivity, either by simple addition of a physical tracer, or synthesis of an isotope into the component. Alternatively, a nu-

clear reactor or particle accelerator could be used to activate the component if it is capable of surviving the destructive effects of the irradiation. After predetermined periods of mixing with the tagged material, samples from different parts of the batch can be compared for radioactivity and the batch mixed until activity is constant; or autoradiographs could be made by placing samples of the mix on photographic film, allowing them to sit for a suitable

period of time, developing the film, and noting the uniformity of the samples by the darkened spots on the film. Once the optimum mixing time has been determined, the tagged batches can be disposed of in some safe manner, and it should not be necessary to add isotopes to the process again until some variable is changed.

There have been a number of suggestions for the routine addition of isotopes directly to a manufacturing process for the purpose of *controlling* the process, but to date these have not been put to practice in America. Aside from possible technical reasons for this, is the fact that agencies concerned with the public's health and safety consider very carefully any proposal for adding radioisotopes to a product that might reach the public, even though the quantity is small. They are particularly concerned about adding isotopes without the public's knowledge. Moreover, the general public is not yet educated (and may never be) to accept the addition of radioactivity to commercial products unless it serves a tangible purpose for the public, such as the addition of radium to watch dials to make them glow in the dark.

The subject of controlling processes brings us to the next feature of radioisotopes — the fact that they are a compact source of radiation. This feature does allow

them to be used for industrial control purposes, but in such a way that they are not added directly to the process or product. Alpha, beta, gamma, and neutron radiations from isotopic sources are transmitted, absorbed, or reflected in a manner characteristic of the material they hit. Thus, an examination of the changes produced in a beam of radiation by an unknown material can provide useful information about the material, for example, its thickness. Radioactive thickness gauges are finding extensive use for measuring and controlling the manufacture of paper, plastic sheet, and tin plate.

More in the nature of a research tool is a device employing radiation from strontium 90 to measure the ratio of hydrogen to carbon in a hydrocarbon. When beta particles from radioactive strontium are passed through a hydrocarbon sample such as gasoline or oil, the attenuation or loss of the particles depends on the number of electrons they encounter in the sample. Since hydrogen has the highest number of electrons per unit weight of any element (in fact, it absorbs just about twice as many betas per unit weight as does carbon), its absorption of the beta particles is greatest. Measurement of betas absorbed by the hydrocarbon sample thus becomes an indication of its hydrogen content. More specifically, when the ab-

sorption value is combined with a measurement of specific gravity (which tells the total weight of carbon and hydrogen per unit volume), one can calculate the weight of hydrogen per unit volume or the ratio of hydrogen to carbon in the pure hydrocarbon sample, which is the desired quantity. The measurement takes only about five minutes and has a statistical probable error of 0.02 weight percent of hydrogen. This time compares with about one to four hours for normal carbon and hydrogen measurements which have a probable error of 0.05 percent. The tool can be used not only for plant and product control but also for research on such problems as altering the percentages of hydrogen in petroleum fuels to improve their performance.

Portable radioactive sources using isotopes such as cobalt 60, cesium 137, and thulium 170 are also used for low-cost radiography of cast and welded metals as well as lower density materials such as plastics and paper to diagnose for defects or to study internal structures, either routinely or as part of a research program.

Examples of the third feature of radioisotopes, their great sensitivity, are numerous. Several American oil companies have determined the rate of wear of automobile piston rings by irradiating the rings in a nuclear reac-

tor, installing them in a test engine, and measuring the accumulation of radioactive iron worn from the piston rings and collected in the oil pan. The results showed a very high rate of wear during the first few hours of break-in; this would have been very difficult to measure by other means, because of the small amount of metal worn away in such a short period of time. Examination of the cylinder wall showed also that relatively large amounts of radioactive iron were adhering at each end of the stroke with less in the middle. Such information is valuable in understanding the physical forces producing wear in an engine and in speeding up the development of longer wearing parts and better lubricants.

The chemical interaction of lubricants with the surface of radioactive steel is also being studied. Any iron which reacts with the lubricant, and dissolves, can be measured with great sensitivity. It is believed that greater knowledge of such chemical interaction will lead to improved lubricants.

A tire manufacturer has tagged automobile tire treads by incorporating in their formula a plasticizer, triphenylphosphate, synthesized from radiophosphorous. He could then obtain a quick measure of the rate of wear of each tire by observing the radioactivity of the

rubber worn from the tire and adhering to the road surface. Because of the simplicity of the test, tread wear could be determined as a function of the roughness of composition of the road surface, of the speed of the car, and of the rate of acceleration in a small fraction of the time and cost normally required. Usually, tire manufacturers maintain large test fleets of cars, and tires that run at least 5000 miles before a measurable amount of wear takes place. Such a procedure provides only a bare minimum of information on such variables as acceleration and deceleration. Yet the radioactivity tests showed that life expectancy of a tire at 60 miles per hour is only 57 percent of that at 30 miles per hour, and that acceleration and deceleration cause even greater wear. Information of this kind should lead to tougher, longer wearing, and safer tires to meet the needs of modern high-speed cars. . . .

An example of the *specificity* of radioisotopes, which allows them to be traced and identified even in the presence of other chemically identical atoms from other sources, is found in an old problem of rubber-product manufacturers. The problem was to learn more about the mechanism by which sulfur vulcanizes rubber in the presence of sulfur-containing vulcanization accelerators. One of the approaches used was to study

the chemical structure of accelerator molecules by radioisotope techniques. Radioactive sulfur in chemical form was heated at vulcanization temperatures in contact with tetramethylthiuram disulfide, a vulcanization accelerator, and the accelerator was then separated and assayed for radioactivity. Activity was a measure of freedom of exchange of the sulfur atoms, and thus indicated the bond strengths of sulfur in different positions of the accelerator molecule. Further evidence on the structure of tetramethylthiuram disulfide resulted from radioassays of sulfur found in the products obtained by destructively heating the tagged accelerator and also from products isolated from vulcanized rubber prepared with the accelerator. The fact that activities of the sulfur in all of these experiments were identical indicated that the tagged sulfur atoms must have distributed themselves uniformly throughout the original tetramethylthiuram disulfide molecule. Therefore, all the sulfur atoms of the molecule must be chemically equivalent. These results lent support to the theory that this accelerator molecule is a planar six-membered ring hybrid with all sulfur atoms having equivalent bond strength. This concept combined with other evidence from related studies threw further light on the complex mechanism of rubber vulcanization.

A cattle-feed manufacturer also has used radioisotope techniques to determine the proper chemical form in which iodine and other vital minerals should be added to salt cake. The object was to prevent the minerals from being washed away by the rain while the cake was lying out in the pasture, and yet to allow the animal to absorb and utilize them after it had licked the salt. Various chemical forms of iodine were prepared from radioactive iodine, and these were incorporated in the salt cake. Their leachability from the salt could be determined by the radioactivity of the rain-water contacting the cake. Radioactivity measurements on the animal's vitals and excreta could show the amount utilized by the animal. The combined evidence showed that dithymol diiodide had optimum solubility for use in salt cake. . . .

My company is currently making another full-scale plant study for a client, this time on molten glass, to determine the flow pattern in a continuous glassmaking process. The work has not yet been published. Radioactive sodium, phosphorus, and barium are being added intermittently to specific small portions of the glass feed materials. Radioactivity of the exit glass and of samples taken at certain key spots in the tank are noted as a function of time after the tagged batch is intro-

duced. This work is yielding information on the holdup time of the glass in the tank as well as the degree of mixing and channeling of the feed materials in flowing through the tank.

By simultaneous addition of radioactive isotopes such as phosphorus and barium, which have completely different radiation characteristics, we can compare the two and obtain evidence of the adequacy of each isotope as a true tracer of glass flow. Phosphorus 32 is a pure beta ray emitter, and its radiation can be stopped by a thin sheet of metal. Barium, on the other hand, emits gamma rays which can easily penetrate the sheet. Thus it is possible to measure one isotope in the presence of the other by noting the total phosphorus plus barium activity from samples without the filter, then measuring the barium gamma rays alone by inserting the filter between sample and counter, and stopping the phosphorus beta rays. If the phosphorus and barium are both true indicators of glass flow, they will behave alike, and their ratio in exit samples will remain constant. Results so far indicate considerable channeling and nonuniform over-all mixing. Final results will be used as a basis for designing an improved glass melting tank.

In the field of metallic corrosion, we used tracers to obtain

evidence which helped settle a law suit for one of our clients. This work is also unpublished. The problem revolved in part around the role of carbon disulfide as an inhibitor of corrosion of brass fire extinguishers filled with carbon tetrachloride plus small amounts of chloroform and ethyl alcohol. To throw light on the mechanism by which carbon disulfide inhibits essentially all corrosion, carbon disulfide was synthesized from radioactive sulfur, and ethyl alcohol was tagged with radioactive carbon. These materials were used separately and in various combinations with carbon tetrachloride and chloroform, and were stored inside the brass extinguisher for several months. Radioactivity showed up on the brass surface in a very thin but tenacious film which was judged by radioactivity measurements to be only about fifty to eighty molecules thick. This was well below normal limits of detection.

The fact that the film contained both radioactive carbon from the alcohol and radioactive sulfur from the carbon disulfide, showed both had contributed to the film.

The relative amounts of radioactive carbon and sulfur found in the film suggested two simultaneous mechanisms of corrosion inhibition: first, a direct reaction between carbon disulfide and brass, probably to form zinc and copper sulfide; second, a preliminary reaction between carbon disulfide and ethyl alcohol to give xanthic acid (a strong organic acid) followed by the reaction of this acid with the brass surface to give zinc or copper xanthate. The radioactivity could not be removed by vacuum treatment, washing, or ionic exchange in inactive solutions, and was thus not due simply to surface adsorption of the radioactivity. Its presence indicated that there was a chemical reaction between carbon disulfide, ethyl alcohol, and brass to form a film on the brass. The film thickness is believed sufficient to account for the corrosion protection observed with normal fire extinguisher fluid containing carbon disulfide.

The varied fields from which these examples have been selected illustrate the great versatility of radioisotopes for industrial research.

On the Back Cover

► URANIUM or plutonium metal is elaborately fashioned into fuel rods like these to make the atomic reactor operate. Among the reacting rods are others, made of boron

steel, which, when lowered into the reactor chamber, stop the reaction. Dropping the control rods is called "scramming the reactor."

**Man-Made Life Chemicals
Will Copy Nature's Pattern**

Newly Invented Life Chemicals

► NEWLY INVENTED chemicals built on the pattern nature uses to keep life processes going were forecast by several research groups at the recent meeting of the American Chemical Society.

Many laboratories are studying phosphorus, lately recognized as the key chemical for starting photosynthesis. Phosphorus combines with nucleic acids and ribose sugars when enzymes and certain metallic ions are present. The source compounds and life chemicals they produce were reported by research teams from American Cyanamid Company's research laboratories, Stamford, Conn., and from the Massachusetts Institute of Technology.

Dr. Robert W. Holley of Cornell University, Ithaca, N. Y., called upon chemists to produce complex polypeptides now unknown whose formation can be foretold theoretically.

Dr. Severo Ochoa, New York University of Medicine, New York, reported a general method for building adenosine diphosphate, called ADP for short, and similar growth chemicals into polymers as in life processes, using azotobacter enzyme. Exchange of radioactive phosphorus will continue the reaction cycle while the

growth chemical thus released is polymerized to a new complex substance in the presence of magnesium ion.

He will extend the method using other enzymes from yeast, liver and cultures of micro-organisms, also other nucleic acids, possibly creating forms of life chemicals unknown in nature.

Chemists can draw finer distinction between organic compounds than the tissues that combine with them can recognize, Dr. Barry Commoner of Washington University, St. Louis, explained, modifying the belief that exact reduplication is the secret of growth. Hence comes the possibility of creating new life forms, whether good or bad.

Virus Made in Laboratory

Disease may result from an unfortunate marriage of a protein with the wrong nucleic acid rather than from invasion of living tissues by a specific bad virus.

This new understanding of sickness as a method of growth may throw light on many other problems of reproduction in plants and animals, Dr. Commoner stated.

He reported success in putting together the infectious virus made

up of a protein and a nucleic acid, neither itself infectious, in work on tobacco mosaic virus done under his direction by James A. Lippincott, a graduate student. Dr. Commoner reported also on behalf of his associates, Drs. Eddie Basler, Jr., and Tung-Yue Wang.

He reinforced the success of this new interpretation by reporting similar results obtained independently at the University of California by a research group headed by Drs. H. Fraenkel-Conrat and Robley Williams. So close were these two teams to achieving their goal that less than two months during the past summer separated their discoveries.

Test tube reactivation of virus material in Berkeley in June and St. Louis in early August opened the door to new hybrids of protein and nucleic acids from tobacco mosaic mutants, which may have new effects on the plants.

If such experiments prove fruitful, Dr Commoner stated the way will be open for experiments probing deeply into unknown areas of biological reproduction.

Microbes Produce Drugs

Microorganisms are now performing steps in manufacturing chemicals and drugs that purely chemical methods find difficult and costly, the American Chemical Society was told also.

Minute organisms produce such wonder drugs as penicillin and

streptomycin, Dr. David Perlman of the Squibb Institute for Chemical Research, New Brunswick, N. J., reminded the chemists. Now, he said, bacteria, yeasts and molds can be harnessed to produce changes in the composition of a number of substances, often in a more efficient manner than can be achieved by purely chemical methods.

These changes result in modification of only part of the substance and are accomplished with difficulty when chemical processes are used, Dr. Perlman said. Usually there is an integration of both microbial and chemical operations to form an efficient process. In the manufacture of vitamin C, the preparation of ephedrine, and the synthesis of cortisone, hydrocortisone and related drugs, both chemical and biological operations are used.

Many of the bacteria, yeasts and molds which are used in these transformations are found in nature as organisms causing food spoilage, or as parasites on plants. The bacteria responsible for the souring of wine to vinegar, or the luminescence of spoiled fish and meats, will carry out useful changes in the processes for the production of vitamin C and acids used in combatting boiler scale. The molds found as parasites on many ornamental plants and flowers have been use-

ful in the production of cortisone or hydrocortisone.

The chemical changes these microorganisms perform when grown under laboratory conditions apparently bear little relationship to those they carry out in their natural environment. It is difficult to predict the potentialities of any particular organism. The fermentation chemist and bacteriologist are continually studying new organisms in the hope of perfecting processes which will replace the more complicated operations devised by the manufacturing chemist.

Hormone Builders Found

Acetic acid, which makes vinegar sour, and the fatty substance, cholesterol, are important body hormone builders, Dr. Ralph I. Dorfman of the Worcester Foundation for Experimental Biology, Shrewsbury, Mass., reported at the chemical society meeting.

Hormones are chemicals made by adrenal, sex, pituitary and other glands of the body.

The adrenals, famous as producers of adrenalin and anti-arthritis cortisone, among other hormones, have been subjected to special study by Dr. Dorfman

and associates. In addition to discovering some of the materials the glands use to build their hormones, the Worcester group has been learning the precise relationships between the adrenal hormones and their metabolic products in body fluids.

By means of these relationships and precise analytical methods developed in the laboratory, it is now possible to evaluate the functional status of the adrenal gland, Dr. Dorfman said.

These advances make it possible to study various types of increased activity of the adrenal glands, which under various circumstances produce sexual abnormalities as well as metabolic modifications including diabetes and high blood pressure. The fundamental knowledge derived from experiments designed to describe the manner in which the adrenal hormones are produced has given us a great insight into the specific biochemical derangements that are associated with adrenal cancer and other adrenal diseases. Knowledge of this type should lead to more efficient diagnostic procedures as well as eventually to more efficient treatment.

One pound of uranium, a piece no larger than a golf ball, if fissioned completely, could produce as much as 2,500,000 pounds of coal.

A vast area of fundamental knowledge, now largely unexplored, concerns chemical and physical properties of materials at high temperatures, and under intense irradiation.

The Food of Cancer Cells

► **PRECISE** diet requirements of certain human cancer cells and a mouse connective tissue cell have been worked out for the first time by Dr. Harry Eagle of the National Microbiological Institute, U.S. Public Health Service.

As a result, cancer researchers should be able to find more quickly and directly the chemicals that might stop cancer by interfering with their nutrition.

Chemicals to fight virus diseases or vaccines to prevent them should also be developed more readily because it is now possible to tell which chemicals in the cell are used by the virus for its life and reproduction.

The cancer cells, Dr. Eagle finds, need the following seven vitamins: choline, folic acid, nicotinamide, pantothenate, pyridoxal, riboflavin and thiamine (vitamin B one).

They also need the following 13 amino acids, or protein building blocks: arginine, cysteine, glutamine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, tyrosine and valine.

Besides this, the cell diet requirements include the sugar, glucose, some still unidentified

protein which is in the blood serum, and salts of sodium, potassium, calcium and magnesium.

When any one of the seven vitamins or of the 13 amino acids was withheld from the diet of the cancer cells, microscopic signs of cell injury developed within a few days and the cells died. In the early stages, the vitamin and amino acid deficiencies could be "cured" by adding the missing substance to the diet again.

Dr. Eagle considers it may be significant that with many of the amino acid deficiencies, the damage to the cells closely resembles that which results from virus infection.

The polio virus, Dr. Eagle found, could live and multiply in the HeLa cancer cells even when amino acids or serum protein or vitamins were withheld from the cell diet. Apparently the virus built itself at the expense of protein or other chemicals in the cell, robbing the cell of them for its own use.

When, however, both glucose and the amino acid, glutamine, were omitted from the cell diet, there was a marked reduction in polio virus production.

Details of the study were reported in the journal, *Science*.

Cancer Research Reports

► OLD AGE itself may be a primary cause of cancer, a team of Indiana zoologists suggested to the American Institute of Biological Sciences meeting recently.

If the same relations hold in man as in the one-celled animals, parameciums, speculated the scientists, an increase in the average age at reproduction might be as harmful to man's heredity as the increase in background irradiation due to the explosion of atomic bombs.

Experiments with the "aged" one-celled animals revealed that the carriers of hereditary traits in each cell, (the chromosomes), often act abnormally with increasing age. As the cells grow older, instead of remaining separate and distinct at the time of cell division, the chromosomes clump together and tear apart unnaturally.

This results in freakish daughter cells bearing hereditary traits different from the parent cells — a situation also found in cancerous cells.

Since cancers are known to appear mainly at advanced ages and to be associated with chromosomal abnormalities of this sort, it may be possible that age-

changes themselves are a primary cause of cancer, reported Drs. T. M. Sonneborn, Myrtle Schneller and Ruth Dippell of Indiana University, Bloomington, Ind.

In their experiments on the aging one-celled animals, parameciums, they also found hereditary damage in the offspring of old parents which caused many weak or non-viable new individuals.

The parameciums used in the tests ranged from vigorous youths of seven days to one-celled Methuselah's of 83 days or older. No paramecium lived longer than 123 days.

Radioactive phosphorus can help tell whether a stomach disorder is cancerous or non-cancerous, Dr. Komei Nakayama of the University of Chiba, Japan, reported at a meeting of the U. S. and Canadian sections of the International College of Surgery.

The radioactive phosphorus, injected under the skin, tends to accumulate in cancer tissue. The location is then disclosed by specially-devised Geiger-Muller counters which are inserted into the gullet, or esophagus, or into the stomach through the mouth. A higher radioactive count is

found where cancer exists, Dr. Nakayama said.

Intelligent execution of this method in combination with conventional methods, such as X-ray study, smear test and others, permits us to obtain a more accurate diagnosis of cancer in the alimentary tract, he said.

The diagnosis was 100% correct, he reported, in 53 cases with malignancy in the esophagus or in the opening to the stomach. Seventeen cases with non-cancers were ruled out. In 58 cases of cancer of the stomach, 56 (96%) were diagnosed correctly before operation. There was a 100% diagnosis of 48 cases with non-malignant lesions. Cancer of the rectum is another good subject for this diagnostic method, Dr. Nakayama said.

Better chemical cancer fighting is being sought through experiments such as those reported by Drs. P. Feigelson, M. S. L. Wu and J. D. Davidson of Columbia University, New York, at the

meeting of the American Chemical Society.

A compound called 8-azaguanine will completely check a specific tumor in mice, it has previously been found. But how it does this and why this and other anti-cancer chemicals lose their effect after a time are puzzles still to be solved.

Dr. Feigelson and associates reported that 8-azaguanine combines irreversibly with a chemical in the body cells called adenosine deaminase. This is an enzyme which helps adenine break down into other substances.

The chemical activity of 8-azaguanine depends considerably on the amount used, but it is active against the enzyme chemical at lower concentrations than those effective when it is used to check the mouse cancers.

The order in which 8-azaguanine and the enzyme chemical are added to the test tube experiments also is important in connection with its chemical effect.

Highest Man-Made Energies

► THE HIGHEST man-made energies ever reached are given atomic particles in the University of California's bevatron, the world's most powerful atom smasher at Berkeley, Dr. Walter H. Barkas reports.

The physicist said that nearly

all of the strange nuclear fragments found in cosmic rays are generated by the machine, which has accelerated protons to 6.2 billion electron volts. The protons, heart of hydrogen atoms, are used to probe the complex structure of atomic cores.

Explosive Fuels

► TODAY'S rocket fuels, fast-burning chemicals which carry with them their own oxygen supply, promise to play an increasing part in meeting special fuel needs and hence bring their peculiar hazards to the attention of industrial and engineering specialists. Sessions devoted to problems in storing, handling and controlling these potentially explosive compounds brought together experts in these problems of the future at the Minneapolis meeting of the American Chemical Society.

Protective clothing made of such synthetic fibers as Dacron and Dynel avoids the fire which breaks out when ordinary clothing is wet with concentrated hydrogen peroxide. This protection, accompanied by a copious supply of water to dilute any of the peroxide chemical accidentally spilled, was recommended by Dr. Noah S. Davis of the Becco Chemical Division of the Ford Machinery and Chemical Corp. of Buffalo, N. Y.

In spite of the fire risk and a relatively high freezing point, this chemical, far stronger than the dilute peroxide solution commonly used for bleaching, is a standard fuel for steam turbines, submarine propulsion and rocket-

assisted take-offs, Dr. Davis said, because of its simplicity and reliability.

Chemicals in the same class as hydrogen peroxide are liquid oxygen-ozone mixtures and fuming nitric acids. These supply oxygen to such rocket fuels as liquid ammonia, ethyl alcohol, aniline mixtures, hydrazine, hydrogen and certain petroleum products. Other substances which supply heat by combining with these fuels include fluorine and chlorine trifluoride.

Familiarity with the use of these fuels of the future was urged by Dr. Paul M. Terlizzi of the U.S. Naval Air Rocket Test Station, Dover, N. J. Monopropellants, whose chemical structures carry both fuel and oxidizer, were listed by him as ethylene oxide, hydrazine, hydrogen peroxide and nitromethane.

Tetranitromethane was recommended as a liquid oxidizer for rocket fuels by Dr. Johann G. Tschinkel of the Department of the Army, Huntsville, Ala., because its great density allows it to store as great a weight of oxygen per unit volume of the fuel as does liquid oxygen itself. Drawbacks in its use are its high solidifying temperature of 14 de-

grees centigrade, or 57 degrees Fahrenheit, and its tendency to explode when mixed with other substances.

Extra precaution in handling liquid ozone was urged by Dr. G. A. Cook of Linde Air Products Company, who pointed out that there are certain concentrations of ozone mixed with oxygen below which there is little danger of explosion but above which explosion becomes more likely as ozone concentration increases.

If high-concentration liquid ozone is to be used as the oxidizer in a rocket fuel system, Dr. Cook recommends, it should be handled by remote control for protection of personnel.

Two ways in which energy can travel back from the hot flame to the cold unburned fuel were described by Dr. O. B. Case of the Allegany Ballistics Laboratory of Hercules Powder Company, Cumberland, Md. These are direct transfer of heat and diffusion of

free radicals. The first of these raises the temperature when a nitrate ester is the fuel until the point is reached at which its chemical breakdown begins. In the second method, chemicals in an unusually reactive state attack the fuel and start its breakdown. Chemists in Dr. Case's laboratory are trying to learn which of these methods has the greater effect in burning nitrate ester fuels and explosives. Similar studies were reported by Dr. Joseph B. Levy, of the Naval Ordnance Laboratory, White Oak, Md., in connection with the use of nitroglycerin and nitrocellulose as fuels and propellants.

Inspection by radiographic methods of fuels in solid form, cast directly into the rocket case, and looked at with a fluoroscope, was described by Dr. Jack Buchanan of the Thiokol Chemical Corporation, who pronounced the technique developed for this inspection a step toward improving reliability and safety of the rocket.

New Method Spots Oils in Pipelines

► A NEW METHOD for spotting where one kind of oil is followed in a pipeline is by bombarding it with neutrons, uncharged atomic particles.

Drs. D. B. Smith and G. R. Church of Britain's Atomic Energy Research Establishment, Har-

well, said preliminary tests showed that fuels can be spotted by a five percent change in reading.

Difference in the hydrogen content of the oil causes changes in reflected or absorbed neutrons that can be measured by standard equipment.

**Sulfur May Join Phosphorus
in Triggering Life Reactions**

Cycles of Photosynthesis

by HELEN M. DAVIS

► THE GREAT race among scientists to see who will be the first to give the most complete account of photosynthesis, the food manufacturing process of the green leaf, comes closer to a finish.

Dr. Melvin Calvin of the University of California, Berkeley, described to the recent National Organic Chemistry Symposium of the American Chemical Society at Purdue University a valve which controls the relationship between two kinds of chemical cycles in plants. Both cycles are fundamental in maintaining life on our planet.

One cycle is that of the sugars. It forms the food that supports life. By alternately building up and tearing down sugars with five and seven carbon atoms, plants add one carbon atom at a time, stepwise, to the structure of the leaves, stems and roots they build in the sunshine. Thus they manufacture food. This fundamental way in which plant tissues are built up has been understood for only about a year past.

The other life cycle, now linked to the sugar transformations, is known by the name of its dis-

coverer, Dr. Hans A. Krebs, of England's Sheffield University. He was honored for discovery of the "Krebs cycle" by the Nobel prize in 1953. In this cycle, citric acid is recognized as a fundamental chemical in many life processes. This is the same substance that is found in lemons and other citrus fruit. It plays a part in the utilization of sugar by the muscles in the animal body.

Working with radioactive forms of carbon and phosphorus, Dr. Calvin and Dr. J. A. Bassham have now found that citric acid, a tricarboxylic acid, appears in photosynthetic products as soon as the light is turned off.

It goes through a complicated but fairly well understood series of chemical transformations in which the elements phosphorus and sulfur play a part.

Sulfur is a close chemical relative of oxygen, the vital element breathed by both animals and plants. The two sister elements can often change places in chemical molecules without making a very noticeable change in the properties of their similar compounds. Dr. Calvin and Dr. Bass-

ham now suggest that sulfur may be the undiscovered trigger that kicks off the circling reactions that make photosynthesis a continuous process in the green plant.

Delicate balance between two alternate kinds of sulfur compounds associated with the sugar cycle and the tricarboxylic acid cycles in living plants may be affected by the energy of sunlight. Light may therefore act as the valve allowing carbon to progress along one pathway while it is shining, shifting to another in the dark.

"This system is like a valve that is closed by light, and that controls the flow of carbon from the photosynthetic cycle directly into the tricarboxylic acid cycle", it is stated in a paper by Dr. Calvin and Dr. Bassham, presented to the Atomic Conference, Geneva. "It suggests further that the disulfide may be closely allied to, if not identical with, the electron acceptor from the photochemical act. Actually a number of experiments have been performed that indicate that this may be so."

Identity of the substance that seizes the hydrogen is the final mystery in the puzzle of photosynthesis. Three steps are taken by the plant in building complex organic compounds from water and carbon dioxide, with the aid of light. Each step, as it has become understood by scien-

tists, has been found more roundabout than had been imagined by early chemists. Yet the mechanisms that have been found working in green leaves have proved simple.

The first step taken by the plant in its chemical factory is to split water into its two elements, oxygen and hydrogen. The oxygen is given back into the air. In the second step, the hydrogen helps break up the carbon dioxide, changing the carbon to a compound more adaptable to the rapidly changing cycle of organic compounds which the plant continually builds up and breaks down.

In the third step, the beginning of the shifting cycles of organic compounds, the leaf calls upon the supply of phosphorus in its tissues to form transitory substances which start the cycles going. The early stages of photosynthesis have been quite thoroughly worked out. Radioactive isotopes of carbon and of phosphorus have been introduced into the plant's tissues. The tell-tale atoms show what becomes of these elements. The sequence of compounds formed has been worked out by shortening the time between the injection of the isotopes and the analysis of the radioactive products that the plant makes of them. But the very earliest substance, the compound that triggers the first attack

on the carbon, has remained a mystery.

Hydrogen is the part of the broken-up water molecule that the plant holds onto. No bubble of hydrogen gas as such is ever let loose by the green leaf. The plant's chemical factory takes the hydrogen ion, with its electrical combining charge, and combines something with it to form an unstable compound. The compound turns into one kind of substance in the dark and another kind when light shines on the leaf.

The energy which the plant uses to make these transformations has been measured. To make the chemical change from one molecule of carbon dioxide, such as the plant would absorb from the atmosphere, to a readily reacting form of organic compound usable in the plant's tissues, the plant will ultimately call into use four electrons, obtained from the splitting of water, plus three molecules of a compound chemists call ATP. The letters are an abbreviation of the compound's long

name, adenosine triphosphate. Since the importance of phosphorus compounds has been recognized, this substance has been known to take an important part in photosynthetic reactions. If the trigger chemical proves to be a known sulfur compound, scientists will know how the mysterious green leaf goes about its work.

When this great advance is achieved, it may lead to the chemist imitating the green leaf and setting up a factory to manufacture sugars, carbohydrates and other foods, beating the plants at their own game.

It is also likely that other complex chemical cycles will be discovered in living plants. As is so frequently the case in scientific advances, the puzzling out of one kind of complexity leads to still others. Probably other cycles additional to the sugar cycle and the Krebs cycle will be found similarly operating to produce the great variety of substances manufactured by living matter.

Ions May Block Minerals Uptake

► WHAT IS IT in the soil that sometimes blocks the uptake of vital minerals into plants? Studies by James Goss of the department of botany at the University of California at Los Angeles suggests that tiny electrically charged bicarbonate ions, abundant in much of the soil of the arid West, inhi-

bit the uptake of phosphorus and calcium. It is known that these two minerals are essential to the growth of plants, but their exact roles in plant processes are not known. By radioactive-tagging of phosphorus and calcium, Mr. Goss has been able to follow their uptake in plants.

Production of Uranium Metal

by L. GRAINGER, *United Kingdom Atomic Energy Authority*

► THE BULK supplies of uranium required for the British atomic energy project have been purchased at the Springfields Works near Preston, Lancashire, first under the Ministry of Supply, and more recently under the United Kingdom Atomic Energy Authority. When the production Division of the Department of Atomic Energy was set up in February, 1946, it had the two primary objectives of designing and constructing BEPO and of producing plutonium. It was clear that the construction of a complete factory for manufacturing uranium metal from ore was an extremely urgent commitment.

At this time some work had been carried out by I.C.I., under contract, to develop methods for producing metal from pure uranium oxide, which was then available from the United States, and this work was approaching completion. No development of the processes to convert virgin ores to pure uranium oxide had been carried out, however, and it was now necessary to provide for these stages also.

Although a basically simple process was finally selected, the

urgency of the project and the special difficulties strongly influenced the choice of process and the detailed implementation. In the first place, since it was desirable not to spend time developing a new site, an existing wartime chemical factory was selected. This enabled much effort to be spared from the construction of road and rail connections, workshops, stores and services and, in fact, by the exercise of some ingenuity it was found possible to house many of the processes for uranium manufacture in buildings previously used for other chemical processes.

A grave difficulty which existed was that only a modest amount of technical information was available on the processes selected, and this mainly on the laboratory scale only. Time was too short to await further research work on these processes and their development on a semi-technical scale and it was decided to proceed immediately to the design and construction of the full-scale plant without intermediate development work. The shortage of research and chemical engineering information had one important effect

on the design of the factory. It is much more difficult to scale up from laboratory bench work to a continuous process on the industrial scale than it is to scale up to a batch industrial process. For this reason batch processes were adopted in most stages in the design of the Springfields Factory.

A third difficulty was that the purity of the final product had to be far higher than is usual in industrial chemical processes. This demand for high purity had to be met by a very careful consideration of the specification for the reagents to be used in the manufacturing process, and by equally careful consideration of the properties of the materials used in construction of plant and equipment, to ensure that they did not give rise to pollution.

The last and perhaps most important difficulty lay in the fact that never before had a factory been built in the United Kingdom in which radioactive material would be handled on the scale of several hundred tons a year. There was at that time little experience available to British industrial medical officers to enable them to give guidance in the design of the plant. It was necessary, however, for them to specify, amongst other matters, the conditions under which massive uranium could be handled and a tolerance for uranium dust in the atmosphere. It is now clear that

the tolerances then properly set were very much on the safe side, but they strongly influenced plant design and operation since the figures stipulated could be met only by exercising the greatest care. It was decided, to carry out as many operations as possible in the wet; where dry salts had to be handled special cabinets or ventilation were provided.

In outline, the process used at Springfields for the manufacture of uranium metal is first to crush the ore and to dissolve this in mixed sulphuric and nitric acids. The solution is filtered to remove impurities and the uranium is precipitated as a crude peroxide. This peroxide is re-dissolved in nitric acid and passed through a solvent extraction process to remove the remaining impurities. The purified material is precipitated as ammonium diuranate and converted into uranium tetrafluoride, which is reduced to the metallic form.

The ore, consisting of fine powder, granular material, or lumps up to 8 in. in diameter, arrives in drums and contains a certain amount of radium and radon. Any radon released on opening the drum is taken up and discharged from the stack of the ventilation system. The ore is tipped into a hopper and fed to a jaw crusher. The discharge from this passes to a screen, oversize material being fed to a cone crusher and

returned to the screen after reduction to about $\frac{1}{4}$ in. mesh.

Sampling of the ore is a matter of great importance because the price paid is based on assay. The sample is taken by feeding the crushed ore to a series of four Vezin samplers which continuously remove a proportion of the feed. The final sample is pulverised in a disc grinder and emerges as 80 B.S. mesh material. It is then coned and quartered to give a number of samples which are distributed between buyers' and sellers' representatives for analysis.

The whole of this crushing and sampling process is done in plant which is not approached while it is in operation. Ventilation of the plant is achieved by two powerful fans which draw air from numerous points through cyclone dust separators and discharge through the air scrubber to a high level stack. The air scrubber is sprayed with water circulating in a closed system; dust removed from the ventilation system is recovered from a labyrinth, drummed and returned to store.

The crushed ore is slurried with water, reduced to about 30 mesh in a ball mill and discharged into a stirred stock tank. The slurry is fed at a controlled rate to the first of three cascade dissolvers, stainless steel tanks fitted with stirrers, to which nitric and sulphuric acids are added contin-

uously according to the uranium content of the slurry. Heating is by live steam and radon and acid fumes are efficiently extracted. The slurry overflows from the first to the second dissolver, which is also heated, and barium nitrate solution is then added to form insoluble barium sulphate and co-precipitate the radium present as sulphate. The mixture then overflows to the third dissolver where it is cooled by a cold water coil, causing further separation of insoluble sulphates. It is then pumped to filter presses which retain all insoluble materials, including the radium and precious metals.

The uranium in the clear liquor from the presses is next precipitated as uranium peroxide by the addition of hydrogen peroxide under carefully controlled conditions of acidity and temperature and is removed from the solution by filter pressing.

The crude oxide is re-dissolved in warm nitric acid to form uranyl nitrate solution. The final free acidity and specific gravity of the solution are carefully adjusted within prescribed limits, and the solution is then evaporated under reduced pressure until it reaches the composition of uranyl nitrate hexahydrate.

The molten concentrate is then pressure filtered through fine gauze to take out some of the impurities, and further purified by

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a single-stage ether extraction. The majority of the uranium is dissolved in the ether, while the bulk of the impurities remain in the aqueous layer which falls to the bottom of the extractor and is run off continuously to stock tanks. The ether layer is then washed with a small amount of warm demineralised water to remove most of the remaining impurities, and finally treated with a large volume of cold demineralised water to wash back the uranium into aqueous solution.

The pure uranyl nitrate solution from the ether purification plant is treated with ammonia to precipitate ammonium diuranate. The yellow precipitate is washed with water in the precipitator and dropped onto a Nutsch filter. Vacuum is applied under the cloths, producing a semi-dried cake which is filled into trays for use in the "Dryway" plant.

It should be noted that at this stage the uranium reaches its highest purity. Up to this point in the process impurities have been progressively removed from it; after this stage it inevitably picks up some impurities from the plant and apparatus with which it makes contact.

The next stage is the conversion of the ammonium diuranate to uranium tetrafluoride, a series of operations which is carried out in the "Dryway" plant. Trays con-

taining the ammonium diuranate paste are stacked in a cylindrical reactor so that reactant gases which are introduced can pass from tray to tray across the surface of the contained solid. The reactor is lowered into an electric furnace, and the conversion proceeds in three stages. The diuranate is first heated to decompose it to uranium trioxide; during this calcination ammonia and steam are driven off. The trioxide is then reduced to dioxide by hydrogen, and finally the dioxide is treated with anhydrous hydrofluoric acid gas to convert it to uranium tetrafluoride. All these reactions are carried out in the same reactor which has a series of connections to the hydrogen and hydrofluoric acid supplies and to a caustic scrubber where effluent gases are either absorbed or discharged to atmosphere if harmless.

The final step is the reduction of the tetrafluoride with metallic calcium. The uranium tetrafluoride is transported in drums to the reduction plant and calcium chips are added, the operations being carried out in an enclosed cabinet. The contents are mixed under an argon blanket by rumbling the drum and finally charged into the reduction mould. This consists of a mild steel casing resembling an inverted, truncated cone. It is lined with calcium fluoride which has been rammed round a wooden former and carefully dried. The

mould is mounted on a bogey running on a light rail track which passes through a long drying oven, through a charging cubicle, into a firing chamber, and out again into a cooling bay.

The charged mould is moved forward into the firing chamber, and vertical, electrically operated doors lowered into position. The charge is fired by dropping into it an ignited pellet of potassium nitrate and lactose mixture. An elaborate system of interlocking controls insures that the charge is only fired when full safety precautions have been observed.

The reaction in the mould is rapid and exothermic. The heat generated melts the uranium formed so that the metal runs down to the bottom of the mould where it forms a solid billet, while the calcium fluoride, which is the other product of the reaction, floats on top as a slag.

When the reaction is complete, the mould is moved forward by remote control into the cooling bay. After cooling, the mould is hoisted into a breakdown cubicle where it is inverted over a grid so that both the uranium billet and the calcium fluoride slag and mould lining fall out of the mould.

The billet is finally cleaned and washed.

From all the wet processes effluent liquors arise and pass into a recovery section. To this section are also sent various solid residues from later stages in the process. The recovery of uranium from these effluents and residues forms an essential part of the whole process and governs the overall efficiency. The basis of all the recovery process is to convert the uranium present in the material to uranyl nitrate, if not already present in that form. The uranium is then precipitated as uranium peroxide, and the recovered material rejoins the main stream at the ether purification stage.

Despite the difficulties and the short time scale for design and construction, the plant has been wholly successful in operation. It started to operate on the programmed date and has from the outset achieved its designed output. This result has been quoted as a classic example of the proposition that, in appropriate circumstances, the elimination of pilot plant work can be accepted and may even be an advantage, since there is no possibility of the designer perpetuating inelegant features of a hastily constructed pilot plant.

Chemists have synthesized chaulmoogric acid, until recently the most common drug used for the treatment of leprosy.

Heat generated by a plane flying through the air at ten times the speed of sound would be great enough to vaporize a diamond.

Not as Easy
As It Sounds

Disposal of Radioactive Wastes at Sea

by CHARLES E. RENN, *The Johns Hopkins University*

➤ AT THIS PRESENT moment there is no practical working program for the continuing disposal of power reactor wastes at sea. Our experience with sea disposal has been limited to small amounts of low level wastes developed in a variety of laboratories and installations.

Detailed analyses of the conditions for safe and economical waste disposal are being made with the aid of leading American oceanographers and waste disposal specialists. The studies, to date, show that a number of misapprehensions exist and that an extensive series of basic investigations must be made, before sea disposal can be recommended. In this paper we will briefly review the hopes and limitations for sea disposal of reactor wastes as we know them today.

It has been pointed out frequently that there are limitless opportunities for disposal of wastes in sequestered areas of the ocean bed. There exist, the argument runs, a number of deep holes, or basins, in the ocean, which contain cold, salt water so dense that they mix very slowly, if at all, with overlying water.

Obviously, if lightly encased wastes are dropped into these areas, or if heavy, saline type wastes are piped down into these basins, the wastes will be contained long enough to permit fission decay to safe levels. We would know where the wastes are, they would be effectively locked up, and the whole operation would be quite economical.

When we examine this concept in detail, however, we discover a number of limitations. First, oceanographers do not agree that such deep areas of stable water exist. If water masses were static for many centuries, the deep water of the ocean floor would warm from heat of the earth's crust. There should be a slight rise in temperature immediately over the sea bottom. The existing temperature data, and there is a great deal of this, shows only a few areas where temperature variations in the deep water exceed those due to pressure. Information on the rate of mixing and turn over of deep water is limited. The more recent critical studies show vertical mixing of the ocean waters to be much more rapid than we had anticipated some years back.

Some oceanographers suggest that the time of mixing in the Atlantic may be as long as 1500 years. Others propose a much shorter time. The problem is of great intrinsic interest and is being pursued intensively by physical oceanographers.

In addition to this, there is some evidence to indicate that there may be periodic and uncontrolled types of overturn due to prolonged variations in the ocean surface temperatures. For example, the existence of oxygen in the deep Atlantic waters strongly suggests that this bottom water must have been at the top not much more than 100 years ago. At about this time a series of severe winters with continuing cold summers may have produced large masses of surface water of low temperature and high density which displaced the stagnant oxygen-free water of an earlier period. Although there is a great poverty of adequate early weather records, the incidents during Napoleon's march on Moscow and other accounts in the history and literature of the time, suggest that this may have been such a period of prolonged cooling. The possibility certainly exists that we may have relatively short period convective overturns of the ocean waters due to unusual local cooling conditions at the water surface.

It goes without saying that oceanographers are greatly con-

cerned with the dimensions of this stability limit. The dimensions of the so-called basins, the rate of flow across rims and low margins are also factors of great concern. While the sonic fathometer has greatly increased our knowledge of the topography of such areas, detailed knowledge of the densities, temperatures, oxygen concentration and other factors require laborious, time-consuming, and expensive deep sea sampling, analysis of carefully-taken samples, and critical correlation of much data.

It has been proposed even more frequently that packaged masses of fission wastes be dropped into one or more of the many deeply cut canyons that break the face of the North American continental shelf. These areas have the advantage of being relatively close to shore, of having well-defined configurations, and being readily located by sonic sounding, and loran navigation. We should know where the waste is, in this case, and we should be able to get to the dumping areas with a minimum of time and cost.

The submarine geologists point out, however, that the canyons themselves are produced by local instabilities. These gullies are scoured at relatively frequent intervals by what are submarine mud slides. There seems to be no disagreement about this. The slides occur every two or three

years, and in some localities often-
er. Detailed observations of the
phenomena are being made on the
West Coast. A number of studies
have also been made on the At-
lantic Coast. Some especially pro-
vocative information has grown
from an inspection of the records
of cable breaks in the areas of
such submarine earthquakes and
land slides. These suggest that
the flowing mud and sand that
erodes the canyon bottom reaches
high velocities, in the order of 15
to 50 miles an hour. Movement
over the bottoms is sufficiently
rapid to keep them scoured hard
and clean; and density currents
project mixed sands and silt for
miles beyond the mouths of the
canyons, a phenomenon that is
demonstrated by repeated strata
of fines in cores that have been
taken in the deeps beyond the
shelf.

This description shows us that
packaged wastes will undoubtedly
receive rough treatment if they
are deposited in the bottoms of
the canyons. We would not, in
fact, know where the waste was.
We could not be sure that it was
being contained. It would be ex-
tremely difficult to conceive of
inexpensive packages designed to
withstand the tumbling, grinding,
and scouring of submarine mud
flows. We know nothing of the
fate of any activity freed in the
deep sea dust storm that develops
with these flows. It is possible

that activity will be absorbed on
the fines. Our limited knowledge
of the degree of uptake and of
the behavior of wastes as they
exist makes predictions impos-
sible.

Another recommendation has
received considerable publicity,
that atomic wastes be packaged
in suitable shaped containers,
flown or carried to sea, and drop-
ped or projected at high velocities
to be buried in the deep oozes of
the sea bottom or in soft delta
muds of our various rivers. This
idea seems to be especially ap-
pealing.

A review of the possibilities
from this method shows that aside
from the rather specialized and
expensive requirements for pack-
aging and transport, there is very
little likelihood that either shaped
or unspecialized masses will sink
into the bottom. First, there are
few accessible places where the
bottom is sufficiently light and
permeable. This word "ooze" has
had especial quality in misleading
thinking on ocean disposal. In
most areas, with the exception of
harbors and recent delta deposits,
the fines of the bottom have
achieved a degree of consolida-
tion that more approximates putty
and stiff clays. Only a very thin
layer exists in unconsolidated
form. Our experience with wrecks,
sunken buoys, and more recently
with mines and depth charges
dropped from planes, shows us

that any degree of useful penetration is extremely unlikely. With the practical densities that can be achieved, marine geologists all agree that the drums, cubes, spheres, shaped objects that rest on the sea bottom would continue to rest on the bottom long past the period of useful decay of the fission products themselves. We would be able to secure natural containment in only a few selected sites. Dumping of shaped charges itself, while dramatic, has little practical advantage in sea disposal. Experiments with cylinders and other shapes show that terminal velocities in the water are usually reached at about 60 feet drop through the water, after which the object tumbles down at a velocity of approximately 20 - 25 feet per second to crash against the bottom. Shaped, finned charges have a somewhat higher terminal velocity, determined by skin friction in water. There would be no gain from dropping these from high altitudes for deep sea disposal.

There are, however, certain soft spots where natural containment of packaged wastes may be possible. Submarine geologists point out that one very desirable characteristic is that the bottom disposal areas themselves may be contained by some sort of natural rim. We have, for example, mud pockets in the Gulf of Maine. They exist in relatively shallow

areas of 90 to 120 fathoms and might be considered accessible. Disposal operations in the Gulf of Maine, a heavily fished part of the world in which deep sea trawling operations are becoming more frequent, at least presents problems in public relations. There are also contained areas in the deeper parts of the Gulf of Mexico, where the bottom is relatively unconsolidated and where heavy masses might be expected to sink for eventual cover.

Disposal in the so-called unconsolidated silts of the estuaries requires a careful and detailed analysis of estuarian geology. Some sections of the Mississippi Delta have histories indicating some permanence.

It is important to view these points critically since it is easy to be plausible in discussions of unknown phenomena, especially in discussions of behavior of the ocean waters and bottoms where our common, real information, practically speaking, is at the level of folk lore. Some time ago a proposal was made that wastes from one of our very large installations be cast in the form of large air-born concrete torpedoes, carried to the coast and dropped off the mouth in soft mud of one of our larger rivers. Aside from the transportation difficulties, a quick glance at the coast and geodetic map would have shown that the area recommended was not a soft,

muddy bottom, but a shallow, coral plateau with a hard bottom, and swept to depths of 300 to 400 feet by the north flowing Gulf Stream. The site certainly represented the least desirable type of permanent burial place. I mention this case as an example of the somewhat superficial type of examination that has been given to the problem of ultimate disposal at sea generally.

We do actually dispose of small quantities of radioactive wastes at sea. Most of this material can be classified as laboratory and experimental installation wastes, including small amounts of concentrates that cannot be disposed locally at several of our coastal AEC and contractor installations. They include broken glassware, experimental animals, reagents, contaminated equipment, cloths and paper, liquid waste concentrates. These are packaged in a variety of ways. One common method is to encase the material in concrete to form packages of sufficient size to furnish shielding for safe shipment, and to weight the mass for the deep sea sinking. Blocks as large as 12 tons are routinely disposed, although most of the sea disposal material of low level concrete embedded wastes is cased in 55 gallon, 30 gallon, or 5 gallon drums. Each installation has its own practice in the preparation of these drums.

The ocean carrier facilities that

are attached to these disposal operations are furnished by reciprocal government services. Along the Atlantic Coast, the U. S. Army disposes of wastes from several installations as part of their waste or outdated ammunition disposal program. These are carried to sea on large ammunition barges and dumped in pre-selected ammunition burial areas beyond the edge of the continental shelf in 1200 fathoms of water. The U. S. Coast Guard also disposes of packaged waste. On the West Coast, the U. S. Navy disposes of packaged trash and waste from its own installations and from Atomic Energy Commission contractor installations. In addition, much smaller quantities of waste are disposed by private contractors as part of salvage and hazardous chemical disposal operations. An even smaller quantity has been handled as a courtesy by oceanographic and marine laboratories having adequate ship facilities. These represent courtesy services to their respective universities.

We may say of these small operations that there is nothing in them that can be applied to disposal of high level wastes represented by reactor wastes. The poundage cost is high, and the type of light, temporary shielding yielded by concrete loaded drums is totally inadequate for individual shield requirements of high level wastes. The costs of these opera-

tions, including all phases, are completely out of line with anything that may be practicably attached to power development. Roughly, experience with low level waste gives us a cost figure of approximately \$10 per cubic foot for final disposal.

In the case of these low level wastes we make no effort to monitor the disposal area, and we have no information whatever upon the durability and condition of the containers. It is reasonable to assume that the levels will never produce hazardous concentrations, even when assimilated by plankton organisms and other forms that may be in the area. A practical working test of the procedure, which on the surface would seem somewhat uncontrolled, and possibly much overdesigned, is that there have been no repercussions from the practice.

The disposal of wastes by private companies from high level operations that may be anticipated from the power reactor development presents many problems that are quite different from those attached to government operations. The possibilities for exchange of service, for example, are distinctly limited. Costs of equivalent labor to private operations are frequently much higher. Even more significant is the fact that surplus labor, or emergency and auxiliary labor required for handling of high level wastes in pre-

paration and transport are unavailable in private operation. For example, it is quite possible, in emergencies, for an AEC or contractor installation to draw on its secretarial staff, machine shop help, or ground crew to assist in a radio-active mop up operation so that the necessary exposure may be shared among a large number of people. This reduces the amount of shielding and special precautions that are necessary in the packaging and handling operations. It is unlikely that our labor unions will favor such exchange of service and quite unlikely that a power operation will contain the reservoir of emergency assistance needed. This requires an entirely different type of design than is possible in experimental units.

At intervals over the past year we have conferred with leading American oceanographers concerning the development of suitable criteria for safe disposal of radioactive wastes at sea. Prior to our review, the Committee on Radiological Hazards of the U. S. Atomic Energy Commission had recommended that all waste disposal at sea be contained in suitable, permanent containers. It is not clear what the structure of such permanent containers for sea disposal might be, but this seems like a safe suggestion in view of almost total absence of information at that time on the magnitude

of the waste anticipated from a working reactor program.

Oceanographers point out that we do not yet have the techniques for determining the boundaries of dispersal from any large discharged mass of free wastes. Some very important unknowns enter. First, we have little previous knowledge of the behavior of heavy, saline solutions injected into large water masses such as the ocean, in dimensions that represent disposal of free waste at sea. Second, we have no adequate monitoring technique for judging the dispersal or containment of any large mass of radioactive wastes. If we are to dispose of some millions of curies of wastes at sea in some hopeful deeps offcoast, we face the primary limitation of precision navigation of the dumping and monitoring vessels. Some fixed point must be established. It appears that deep sea buoys represent the simplest and most satisfactory method of marking the burial site and the area to be monitored. The type of activity sensing equipment required represents another special problem. If such equipment is to be lowered and powered through cables, the reliable performance and useful life of a power conducting cable becomes a limit. The pressures developed by winding two miles or more of conductor type cable on a winch drum are very great. These combined with the chang-

ing tensions upon such a system restrict reliable life of a unit fed and sensed through a cable to 20 or 30 lowerings. The time required for such a sampling program is great and the operations conducted by specialists are necessarily expensive. There are also unsolved problems of background level and error induced by absorption of activity upon the submerged equipment itself. These are limitations that cannot be taken lightly. Ideally, of course, a system of automatic monitoring by a grid of planted equipment capable of delivering a signal to a surface station is most desirable, but this is still in the dream stage. So far we have not even developed design plans for an experiment to determine the pattern of diffusion and movement of free wastes in the sea.

Such an experiment is necessary. Although the volume of the sea is great, mixing in the whole ocean is unlikely. Wastes may be expected to move much more rapidly in horizontal mixing than in vertical mixing, although the vertical dimension adds a most important element. In design of dispersal experiments we must know where to look for the wastes and must have some idea of how much will be at sampling points. Precision sampling represents a great instrumental and technical problem.

The biologist, marine ecol-

gists and fisheries investigators are concerned with the potential hazards associated with assimilation and concentration of fission products by plants and animals in the sea. In the short lived category of fission products, iodine would appear to be most significant. This, fortunately, has a short half life. Strontium and cesium are more significant in aged wastes. Some marine forms are known to substitute strontium for calcium in their structure and it is possible that this component will be concentrated. Little is known concerning the fate of cesium.

It is anticipated, from experiments with other natural waters, with silts and with absorbing surfaces, that much of the strontium and cesium in the water will become associated through absorption or reaction with particular stuffs of the sea water system and that these will follow the sediments.

There is some apprehension of the effects of high levels of activity upon societies of marine plants and animals. Interdependent communities are more sensitive to changes in the environment than individual species. A small change in predator population, for example, permits a large shift in the food species, or a small decline in food resources may wipe out a species that is not directly sensitive to radiation. Ecological

changes are, of course, possible, and so far we have made no attempts to assess them quantitatively in the sea.

A very large fraction of the cost of ultimate disposal of reactor wastes promises to come from the cost of shielding required for safe transport, and from shipping costs of massive shielding. Heavy shielding must be provided if the waste is to be moved by common carriers, and if it is to move through shipping centers. If expendable shielding is used, the costs of return shipping will be saved, but the costs of expendable shielding must be entered. Concrete appears to be the most economical combination container and shield that may be expended. Concrete, with relatively low density, on the other hand, has bulk and structural limits.

A transportation system that uses returnable permanent shielding permits the use of denser, stronger, and less bulky structures, but increases capital costs and return shipping costs will be almost identical with the outgoing costs. The waste discharged to the sea from permanent shield containers, or as an unshielded solid or liquid will ultimately mix with sea water.

We have had some experience with the surface disposal of dense, inactive liquid industrial wastes. In the cases that were studied, it

was interesting to discover that dilution proceeded so rapidly during the downward travel of the waste in the sea that dilutions of roughly a million times were achieved through one hundred feet vertical profile. This emphasizes the relative magnitude of horizontal mixing in the sea.

Very clearly then, any liquid bulk wastes must be discharged directly into the stratum where dilution is desired. It also indicates the degree of precision required in sounding and sampling during monitoring and experimental operations—it is impossible to know, at the moment, within 200 to 300 feet where the sampling equipment may be at the end of a 20,000 foot line. The behavior of a weighted cable suspended in the open sea is not comparable

to the conductor of an oil well probe.

Physical and chemical oceanographers and marine biologists have been interested for some time in the potentialities of disposing of radioactive wastes at sea. Only recently, with the development of the fission industry, have they become acquainted with the magnitude of the waste problem. It must be realized that we have few specialists in the sciences of the sea who can guide us, and that these men are occupied with a wide variety of problems. We will need their help, and we will need to help them to enlarge their studies rapidly to provide necessary information of the sea. If the fission power industry becomes a reality, we will need to know much more about the ocean than we do now.

Traps Allergy Causing Molds

► IN ORDER to trap and count mold spores in the air which might cause allergy troubles something as pollen grains do, a filter of a kind of seaweed wool has been developed.

The wool is made of sodium alginate, but since this seaweed chemical is not available as a wool, it has to be prepared from calcium alginate yarn.

The seaweed wool filter traps the mold spores for counting purposes and also allows them to be grown on culture media for identification.

Details of the making and use of the filter are reported by Dr. Merfyn Richards of the Canadian National Research Council's Prairie Regional Laboratory in Saskatoon, Sask., to the scientific journal *Nature*.

Choosing a Research Reactor

by L. KOWARSKI

This brief survey of the essentials of reactor technology is intended for the quick orientation of those who may be called to take part in an early discussion as to whether a given institution should embark on reactor research, and if so, with what type of reactor. More definite decisions can be taken, of course, only on basis of detailed knowledge of the proposed types for which the descriptions given in the current declassified literature are usually adequate.

► FOR AN OVERWHELMING majority of the uses to which a research reactor may be put, it is important that inside its material assembly there should be space in which numerous free neutrons are present at any given moment.

Neutron density usually is measured as the aggregate length of track which the neutrons leave behind them as they traverse the unit volume in a given time. This total length (cm per cm³sec) is called "neutron flux"; it can be imagined as arrived at by counting each neutron multiplied by its velocity. Since neutrons of different velocities act on matter in a

different way, it is customary to divide them into velocity classes and to count these partial fluxes separately. The two most important classes are: (a) neutrons which have yet all the original velocity with which they came out of a fission ("virgin flux"); sometimes this class is widened as to include all those whose velocity stays above a certain limit (corresponding to, say, 1 MeV; "fast flux"). (b) In reactors using the slowing-down process (as is the case of nearly all reactors considered in the present report), by far the greater part of the useful life of a neutron is spent in a state close to the velocity equilibrium with the surrounding medium. The partial flux corresponding to this range of velocities ("slow" or "thermal flux") is often considered as *the* "flux" characterizing a reactor. The most powerful research reactors existing at present produce a maximum slow flux of a few times 10^{14} neutr. per cm². sec. Reactors run deliberately at very weak power levels may produce as little as 10^7 .

High fluxes (useful for research) are connected with high powers (useful for most other

purposes) but not coincident. In a *given* reactor, the flux observed at a given moment is directly proportional to the total power which the reactor produces at that moment. But two *different* reactors run at the same power may produce very different flux values. The other relevant factors are:

(a) The total volume of the reacting medium: what counts for the flux, is power produced in a unit volume. Since power as such is of little interest for research purposes, compact design will be preferable.

(b) The lifetime of the neutron within the medium. Power level determines the rate of their birth, but the population numbers also depend on the rate of disappearance. An irreducible minimum is set by the fission process itself and the amount of fissile nuclei in the medium. Other causes of removal of neutrons are: absorption by nuclei associated with the fissile material (U 238; also other elements used as sheaths and carriers: see below); absorption by other substances present in the reacting medium (moderator, cooling circuits; extraneous bodies such as controlling and experimental devices); streaming ("evaporation") off the surface limiting the reacting volume.

It results from the foregoing that search for a high performance in the design of a reactor is inseparable from a certain number

of compromises. We may mention:

- the conflict between the highest power extraction rate (efficient cooling devices, see below) and the shortening of neutron lifetime due to these devices;

- a very compact reacting core loses many neutrons through evaporation;

- every attempt to use the flux by inserting bodies to be irradiated, providing experimental facilities, or removing neutron beams outwards reduces the maximum flux; we have a choice between a higher flux available for fewer uses, and the contrary.

The last mentioned dilemma exists also as regards the size of the reacting core. A very compactly designed research reactor gives more flux per unit power, but fewer experimental facilities than a more loosely-built one. The best way out of this contradiction is to build *several compact* reactors, but a community which for any reason decides to build only one reactor is somewhat less interested in compactness.

In a reactor designed for a high slow-neutron flux, *fast* neutrons present are considerably smaller in numbers but since their velocity is thousands of times higher, the fast *flux* is lower than the slow flux by a not very big factor. The best conditions for reducing this gap are not most favorable for maintaining a high slow flux;

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hence another compromise to be observed by designers who want both fluxes to be as high as possible. A high fast flux is, of course, useful whenever, in a given research item the interest is focused on the interaction of *fast* neutrons with matter (such a bias can be given to solid state studies, cross-section research, preparation of radioactive isotopes). In any reactor a high *local* value of fast flux can be obtained by using the "converter" device (a suitably shaped mass of uranium which gives off fast neutrons if subjected to a high *slow* flux).

Nature of Nuclear Fuel

All nuclear fuels used at present contain either U 235 or plutonium. "Natural fuel" is the isotopic mixture of the two uraniums 7 kg fissile U 235 per ton of mixture), as it is found in nature; "pure fuel" is nearly pure U235 (as obtained by isotope separation), or plutonium (as obtained by transmutation of U 238). Intermediate fuels may be "slightly enriched" (say, 10 or 20 kg of U235 per ton), or "medium enriched" (such as the fuel made available under the International Pool Agreement and which may contain up to 200 kg per ton), or "highly enriched" (about 90% pure, as used in many American research reactors). Extraneous atoms are however present even in the pure fuel, whether U 235 or Pu, since it has to be used in the form of a chemical

compound or an alloy, or in conjunction with a carrier substance.

The most commonly used types of fuel are at present:

(a) Natural uranium, usually in the form of pieces of chemically pure metal. They are usually cylindrical (short or long, full or tubular) and wear a thin metallic sheath ("cladding").

Main advantage: availability in a nearly free market. Basic disadvantage: absorption of neutrons by the preponderant U 238 leaves few neutrons available for other losses. The three resulting disadvantages are:

1) In a given volume, the ratio of neutron births to neutron deaths is unfavorable; hence, for a given rate of heat extraction, the flux is weak.

2) To limit internal neutron losses, only the least neutron-absorbing materials, and those only in limited amounts, may be used for cladding and in the construction of the reacting vessel and of its internal cooling, controlling and experimental devices.

3) To limit surface neutron losses, the volume of the reacting medium must be great. This aggravates the necessity, already mentioned, of extracting great amounts of heat for a given flux; in fact for each kilowatt extracted from a current-type enriched-fuel reactor, we may have to take as many as 100 kw out of a graphite-

and-natural U reactor if we want to obtain the same flux in both cases.

This enormous increase in the necessary power level aggravates all safety problems and necessitates costly engineering structures outside the reactor proper. To sum up: compared to an enriched-fuel research reactor, a natural-uranium one is crude, costly and less safe. Nevertheless, many research reactors of this type have been, and probably yet will be, built; the advantages of availability may be decisive if the required flux is not too high. It should also be said that for various types of *production* reactors, the disadvantages of natural uranium are far less decisive and a community which wishes to combine research with a pilot design for a producing system may well decide to make a start with natural fuel.

(b) Chemical compounds of highly enriched uranium. The most commonly used compound is uranyl sulfate dissolved in ordinary water.

(c) Highly enriched uranium alloyed with many times its weight of aluminium. This alloy, sandwiched between Al sheets, constitutes the "fuel plate" and several plates, held in an Al box, constitute a standard "fuel element".

Absorption by Al tends to thin out the available neutrons; with a minimum of Al, more flux is

obtained per kilowatt of reactor power. Since tendency is toward higher fluxes, it may be expected the future designs of fuel elements will tend to reduce the Al content.

This type of fuel is likely to assume a preponderant place in the research reactor field. It has already this place in the U.S. practice and, as enriched fuel becomes available to a greater number of nations, this preponderance will spread. Medium-enriched uranium (up to 20%; see above) can be used in the same way, although the U238 atoms present in the fuel diminish the flux-generating efficiency in the same way as aluminum does. At 20% enrichment this decrease is noticeable but in no way decisive for the reactor design. Plutonium, whenever available, may in principle be used in the same way, in similar fuel units, although the metallurgy of its mixing with the carrier may be in practice somewhat different.

(d) Slightly enriched uranium (15 kg or so, of total U 235 per ton of U) may become available in the future as a first, and militarily innocuous, step of isotope separation. Its presentation must be different from that of richer sorts, since U 238 is plentiful enough to act both as a carrier and as flux inhibitor.

As regards the disadvantages mentioned first and third under (a) above, it will be found that

slightly enriched uranium is intermediate between the natural and the rich grades. The second disadvantage, on the other hand, is greatly attenuated even at the slightest enrichment. In other words, a reactor of this type, compared to a rich-fuel one, is still somewhat costly and less safe, but, contrary to a natural-uranium one, it need not be technologically crude.

Two important aspects of the fuel question may be mentioned here. The *cladding* problem in research reactors is far less important than in productive ones, since there is little need for high temperatures, unusual mechanical stresses or corrosive liquids. Only in gas-cooled natural-U types there are serious difficulties to solve in connection with this problem.

The *length of stay* of a fuel element in a reactor depends on many causes of limitation, most of which are simply proportional to the flux. This goes for the radiation damage which tends to throw the element out of shape; for the mechanical, thermal and corrosional fatigue (chiefly in natural-U reactors); for the poisoning by fission products and finally for the simple depletion (which is the dominant cause in rich-fuel types). The following rule of thumb may be of some use: in low-energy reactors (those not requiring any cooling), the

length of stay of the fuel is practically indefinite. In cooled reactors giving flux under 10^{13} , the lifetime of the fuel may be counted in years (many, or at least a sizeable fraction). Above 10^{13} the useful life is counted in months or weeks.

Moderators and Reflectors

In most research reactors, and certainly in all those which have been declassified to any marked degree, the chain reaction is propagated by *thermal* neutrons, which means that the reacting medium, in addition to fuel, must contain a high proportion of light-weight "moderating" atoms. The juxtaposition of fuel and moderator may be homogeneous (solutions of U salts), or arranged in a spatial lattice (a certain degree of spatial segregation is structurally convenient and moreover, whenever the fuel contains considerable amounts of U 238, becomes necessary for nuclear reasons).

Moderators used at present are:

H (light hydrogen) in the form of H_2O (other compounds, such as plastics, can be used only at lowest fluxes because of radiation damage).

D in the form of heavy water,

Be, usually in the form of beryllia, BeO ,

Carbon in the form of synthetic graphite.

The *advantages of H_2O* are: zero cost; highest slowing-down efficiency per cm of neutron path, hence the possibility of achieving the reaction in a minimum volume; possible use as a coolant, which makes possible a simplified reactor design; ability to maintain, in a given medium, a high ratio of fast to slow neutrons. *Disadvantages:* relatively high neutron absorption (thins out the thermal flux). The very compactness of the water-moderated reacting medium may become a disadvantage if one wishes to maintain the reaction in a fairly large volume in order to accommodate many experimental facilities.

The *advantages of D_2O* are: good slowing-down efficiency (not so good as H_2O , better than C or BeO); possible cooling functions (like H_2O) and above all, practically no neutron absorption (important in conjunction with poorer fuels; very important in techniques based on natural U). *Disadvantage:* high cost.

The *advantages of graphite* are: low cost; solidity (which is put to use in some very simple designs, as for instance in low-pressure air-cooled reactors); resistance to high temperatures. *Disadvantages:* appreciable neutron absorption (not as bad as H_2O , so that graphite is still usa-

ble with poor fuels); lowest slowing-down efficiency.

This balance of advantages and disadvantages points overwhelmingly to the use of graphite, as a moderator, in conjunction with cheaper fuels and least advanced technology. In the present research reactor techniques, moderation by graphite occupies a rather unimportant place; it had a greater importance in the past when lower fluxes were aimed at, and refined materials were less easily obtainable, and may become important again if the trend in research reactors reverts toward higher temperatures.

Beryllia is on the whole comparable to graphite; its much higher cost offsets its somewhat greater efficiency as slower-down.

An additional layer of a moderating substance is usually provided around the reacting medium for the purpose of sending back some of those neutrons which tend to escape from the outer surface of this medium. Such a *reflector* exerts a doubly beneficial effect on the flux to total power ratio (it reduces both the power necessary to extract from a unit volume in order to maintain a given flux, and the total reacting volume necessary to sustain the reaction).

For reflectors the high density (atoms per liter) is rather more important than moderators; low

atomic weight is somewhat less useful and appreciable neutron absorption somewhat less prohibitive; otherwise the requirements are similar. This shifts the balance in favour of beryllia, the other three competitors ranging in the order: heavy water, graphite, light water. Two other considerations are: cost (which makes beryllia particularly desirable for reactors moderated by light water, since in these the reacting volume is smallest, and therefore can be surrounded without expending too great an amount of reflecting substance); and simplicity of design, which confers an additional preference on using the same substance as both moderator and reflector. This structural unity of the "core" (reacting zone) with the reflector is customary in graphite-moderated, and in many types of water-moderated reactors: in the latter, the capacity of the tank containing H_2O or D_2O may considerably exceed the volume necessary to maintain the chain reaction and the fuel lattice occupies only a central zone of water-filled volume, so that the fuel-carrying core is surrounded on all sides by (at least) a few decimeters of water.

The device of composite reflection may be resorted to. Heavy water is an efficient but expensive reflector; it pays to use it in a fairly thin layer and to dispose, outside the water-tank, an addi-

tional and cheaper layer of graphite. In H_2O -moderated reactors the situation is reversed: cheap but inefficient, ordinary water is best used as a second (outer) reflector which means that the water tank is big, and that a hollow polyhedron built of BeO or C is immersed in it so as to surround the core on (if possible) all sides.

Cooling

The operation of a high-flux research reactor produces great quantities of heat in a small core volume; this heat has to be removed in order to avoid the disruption of the core. Contrary to what takes place in power-producing reactors, the removal of heat from research reactors is to be considered as a means rather than an end and can be carried out with little regard to the quality (temperature) of the outgoing heat flow. This indifference simplifies the construction of the circuits which carry the coolant through the reacting core; their low working temperature widens the choice of circuit materials; corrosion dangers are minimized and high coolant pressures can be more easily withstood. Only in the highest-flux reactors (around 10^{14}), where the rate of heat removal per unit volume approaches the ultimate possibilities offered by the contemporary engineering, does the necessity of maintaining high temperature gradients reappear in some designs.

Zero-power and low power research reactors present no cooling problem; as the power approaches the 10-kilowatt range, or the flux some 10^{11} , the necessity for some fluid to move continuously through the reacting volume begins to appear. At that stage, for the reactors using ordinary or heavy water as moderator, there is the convenient possibility of using the motion of the water in bulk, which takes place by natural convection, if the core is provided with openings leading to a much greater mass of water or to an external heat exchanger.

Whenever this system cannot be used, or is found insufficient to reach the desired power and flux levels, the cooling fluid has to be forced through the reacting medium. The simplest case is:

(a) Gas in an open circuit. The only gas plentiful enough to be used for a single passage is air in which no high compression work has been invested, that is circulated at a low pressure. Advantages: extreme simplification of the cooling channels and of the disposal after passage (into a high chimney). No engineering and corrosion problems. Disadvantages: large-size blowers and ducts, fairly high power consumption.

The practice has shown that this system cannot compete with the natural convection mentioned above and is therefore applicable

only to relatively low-flux reactors composed of graphite and natural uranium. The limitation of its efficiency comes simply from the fact that there are too few coolant molecules which can pass through the core in a given time.

(b) If used in a *closed* circuit, the gas can be compressed, thus increasing the number of passing molecules and the efficiency (better heat removal and lower power consumption). Fluxes of the order of 10^{13} become possible, so that this system can compete, to some extent, with the cooling by liquids; it presents the advantage of minimizing corrosion problems and it can stand high temperatures (but, on the other hand, it requires them). On the whole this sturdy, but somewhat clumsy, way of cooling is best suited for those reactors which are built as a preliminary step towards industrial applications.

(c) Cooling by *water*: either ordinary or heavy water may be used. Advantages of H_2O as compared to D_2O : low cost, simplification of outside pumping and heat-exchanging devices, since leakage can be afforded. Advantages of D_2O : low neutron capture (important in systems where neutron economy is strict, above all in conjunction with natural uranium); elimination of the contamination risk (in reactors which already contain heavy water as moderator).

Both kinds of water present, as coolants, the common advantage of offering the highest number of heat-removing atoms per unit volume (as compared not only with compressed gas, but also — to a smaller but significant extent — with liquid metals); and the common disadvantage of requiring highly pressurized vessels and ducts, if any but the lowest working temperatures are to be adopted. Since in research reactors the accent is on high fluxes (reduced working volumes) rather than on high temperatures, the balance of advantages of water as a coolant is particularly favorable in the research reactor domain. For this reason we mention only very briefly:

(d) Cooling by *liquid metals*, to be used only if high temperatures are essential, or wherever it is necessary to avoid the presence of a moderating substance (as in the laboratory prototypes of fast-neutron reactors). Liquid sodium or sodium-potassium alloy (lower-melting, hence easier to handle, but less efficient as a heat remover) have been used so far; the use of bismuth is considered in some advanced projects.

Shielding

On the outer surface of the reflector neutron density, although much weaker than in the core, is still much too high to be safely approached by personnel; gamma-

ray intensity is even less attenuated. Core and reflector must therefore be surrounded on all sides by a neutron — and gamma — absorbing medium. The first of these two aims is best achieved by a substance consisting of lightweight atoms, the second by a heavier one. The combined shielding may be achieved by two successive layers (say water followed by a metal), or by using a substance containing both kinds of atoms. Since heaviest metals are costly, the tendency is to use concrete (which contains, as light atoms, some H_2O and more O combined to Ca) loaded with iron or barytes. The heaviest loadings (concrete density up to 6) are costly and used only with the highest-flux reactors; in most cases densities of about 3.5 are sufficiently effective.

From a vast practical variety of shapes and thicknesses, the following general remarks can be abstracted:

- 1) Reactors of zero or a few watts' power require no protective shield;
- 2) The core-and-reflector volume in research reactors fueled by natural uranium is so big that the radius of this volume is greater than the thickness of the concrete shield. If the concrete layer has to surround such a great inner volume, the total volume may become enormous (1000 cbm or more) and the total weight of

concrete may run into thousands of tons.

3) In most up-to-date research reactors, however, the radius of the core-and-reflector volume is comparable to, or shorter than, the protective thickness. The total volume (overwhelmingly concrete) is therefore much smaller and within a small factor, is of the order of 100 cbm.

4) The outer shape of the shield (and, therefore, of the whole reactor) should theoretically, be spherical but in practice is determined by the possibilities of construction. A near-cube is probably easiest to build, but the present tendency is toward octagonal (or dodecagonal) prisms tapering off pyramidally towards a narrower horizontal upper platform.

5) If the concrete contains some added boron, the necessary thickness is somewhat lower, which may result in a reduction of cost.

6) In some H_2O -moderated and cooled research reactors the core is surrounded by a considerable bulk (of the order of 100 or 200 cbm) of water which serves as a first protective shield in some directions.

These orders of magnitude show the interest, from the economy point of view, of compact design and—therefore—of enriched fuels.

A structural complication comes from the necessity of avoiding the excessive heating of the concrete.

In high-power research reactors there usually is a layer of heavy metal (a few centimeters of iron or lead — “thermal shield”) interposed between the reflector and the concrete. Air or water cooling of this layer is a simple problem, since no specifically nuclear difficulties are involved.

Experimental Equipment

In all reactors, whether intended for research or not, the control of operation is based on the direct interference with the rate of production or (more often) the rate of disappearance of neutrons in the reacting core. The most frequently used device consists in moving a neutron-absorbing mass (“control rod”) with respect to the core. In liquid-moderated types the level of moderator in the reacting tank can be varied; in compact types, motion of reflecting elements, or of the fuel itself can be very effective.

Such controlling devices may be operated by hand, or harnessed automatically to an instrument which measures the power level and, at any rate, arranged so as to stop the operation (“safety rod”) if, for any accidental reason, the power level oversteps a pre-set allowed maximum. Their construction and coordination with radiation-measuring apparatus have by now reached a high degree of elaborateness and reliability since their nature is the same in all research reactors, and their

cost is never one of the major budget items, their technology is hardly relevant to our present enquiry. The same can be said of the radiation measuring apparatus itself which is standard electronics.

The situation is different with the *experimental facilities*. When choosing a reactor design, it must be remembered that the most powerful chain-reacting device is hardly of any use if no radiation can be taken out of the reacting volume, and no material specimen can be put into it or close to it. But, on the other hand, every facility to do so interferes with the reaction itself, increases the necessary amount of ingredients, decreases the efficiency of reflectors and shields and complicates the problems of cooling and of personnel safety. A balance has to be struck between these conflicting considerations, all of which have an incidence on the cost of the project.

Most of the experimental facilities take the shape of channels leading through the shield and the reflector towards the edge or the inside of the core. Most channels are associated with specialized equipment, according to their intended use, such as collimators and shutters for the radiation beams; special shielding plugs to be inserted after the necessary apparatus or material has been introduced inside the pile; layers

of appropriate substances necessary for filtering the desired kind of radiation (such as bismuth used to obtain gamma-free beams of neutrons, or uranium which converts slow-neutron beams into fast ones); mechanical or pneumatic conveyor devices for subjecting samples to quick irradiations; thermostats for irradiation at a constant temperature.

Highest-flux regions of a reactor can hardly be reached otherwise than through these specially arranged channels (the term "beam hole" or "beam port" covers most of these, except for some very specialized types). Some use can also be made of openings normally used for the introduction and extraction of fuel; or a fluid substance to be irradiated may be circulated, instead of the coolant, through an isolated section of the cooling network. For irradiations requiring big volumes, cavities can be arranged in the shield; if filled with graphite or beryllia, they are called "thermal columns". Water-moderated and shielded reactors are particularly suitable for experimentation with bulky specimens.

The total number of beam holes and other irradiation openings in a research reactor should be at least of the order of 10; in less compact types this number may go as high as several dozen. As a representative example, we reproduce below the list of the main

experimental facilities permanently attached to a modern high-flux reactor (CP5) in which a compromise was sought between compactness and availability of a conveniently wide experimental volume (dimensions across the opening are given in inches):

- 1 channel reaching to the center of core, 3"
- 7 channels reaching to the outer regions of core, 3"
- 2 beam holes, 12"
- 6 beam holes, 4", two of which positioned with a special regard to fast-neutron flux,
- 2 beam holes across the reactor, passing near edge of core, 6"
- 1 pneumatic through-channel,

passing near the core, 2".

2 holes for biological irradiation, outer region, 8" x 12"

2 thermal columns, outer region, 60".

Some smaller facilities also are available, bringing the total number of experimental openings to about 50.

Ample space outside the reactor, close to the shield, should always be provided. The necessary floor space has been estimated at about 5 sq. meters per experiment. Since heavy shielding of apparatus is often necessary, the floor should be strong enough to support several tons per square meter.

Sulfur Isotopes Date Oilfields

► COMPARISON of heavy and light sulfur in crude oil may furnish the clue to age of the petroleum deposit and history of its formation.

Chemical studies comparing the proportions of sulfur isotopes in petroleum show that, although they are constant for each oil-field they vary widely in different parts of the world. This contrasts with the fact that the sulfur content of sea water is constant in all the oceans of the globe.

These leads toward determining the relative ages of oil fields were reported by Dr. H. G. Thode of Hamilton College,

Hamilton, Ontario. Dr. Thode has studied the proportion of sulfur isotopes collected by chemical processes in different formations of the earth's crust. Native sulfur deposits, he finds, have been formed by bacteria which reduce sulfate deposits. Sulfates tend to have a larger proportion of heavy sulfur 34, while sulfides are relatively poor in this isotope. By study of the occurrence of such compounds, Dr. Thode hopes to piece together the history of sulfur-containing deposits in the crust of the earth. Dr. Thode reported his findings to the meeting of the American Chemical Society.

For the Home Lab

Sulfonation

by BURTON L. HAWK

THUS FAR we have discussed the introduction of oxygen, nitrogen, hydrogen, and the halogens into organic compounds in reactions of oxidation, nitration, reduction and halogenation.* Now we would like to consider the introduction of sulfur in a sulfonation.

Sulfonation is the process by which the sulfonic acid group ($-\text{SO}_3\text{H}$) is attached to an organic compound, usually to the carbon or nitrogen atoms. Of course, we immediately think of sulfuric acid as the logical sulfonating agent. And so it is, although in most cases it is very slow acting. For better results it is often necessary to intensify its action by increasing the SO_3 content (fuming sulfuric acid). Sometimes sulfur trioxide alone is used as the sulfonating agent. In other cases, chlorosulfonic acid is used.

Since neither fuming sulfuric acid nor chlorosulfonic acid are particularly recommended for use in a home laboratory, we shall use sulfuric acid alone even though it does take longer to accomplish

its mission. We shall attempt to prepare sulfanilic acid by the sulfonation of aniline.

First, it is important that the aniline be freshly distilled. Distill about 10 cc immediately before you begin the sulfonation reaction. Place the distilled aniline in a small Florence flask and carefully add, in small portions, 15 cc. of concentrated sulfuric acid. Shake after each addition. The reaction will be somewhat vigorous and it is best to cool the flask after each addition by immersing it in a container of cold water. The white lumps that separate out are aniline hydrogen sulfate.

The mixture must now be heated in an oil bath at 190 deg. for about four hours. The oil bath will enable you to control the temperature more evenly than otherwise. For this purpose ordinary vegetable shortening, such as "Crisco" or "Spry" will work very well. Place the shortening in a large beaker. Heat until it has all melted, then immerse the flask in the liquid fat (see diagram). Place a thermometer in the liquid in the flask and apply heat to the beaker until a temperature of 190 degrees is reached. Then regulate

* See CHEMISTRY Feb. and Mar. 1954 — oxidation; Oct. 1954 — nitration; Nov. 1954 — reduction; Feb. 1955 — halogenation.

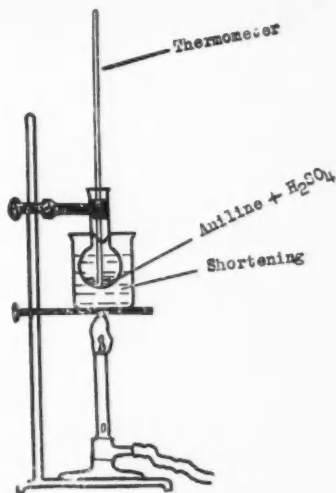
the heat so that this temperature is maintained as closely as possible.

After about four hours, you can test the solution to see if the reaction is completed. Place a few drops of the liquid in dilute sodium hydroxide solution. If, after stirring, the solid dissolves the product is ready. If a separation or precipitation of aniline is obtained, the mixture must be heated longer.

When the reaction is completed, as determined by the above test, pour the contents of the flask into a beaker containing approximately 100 cc. of cold water. Stir rapidly to avoid spattering. Crude sulfanilic acid is precipitated as a grey powder. Filter off the powder and wash it with cold water.

Purify the acid by dissolving the precipitate in the smallest amount of boiling water possible. Add about one gram of decolorizing charcoal (or bone black) and boil the solution for five minutes, stirring occasionally. Filter the solution quickly while still hot and set the filtrate aside to cool. As the solution cools, crystals of purified sulfanilic acid separate.

As you have probably deduced by now, sulfanilic acid is only sparingly soluble in cold water, much more so in hot water. It is soluble in sodium carbonate solution with the evolution of car-



► SULFONATION of Aniline.

bon dioxide. You can try this to test your product.

Sulfanilic acid is used in the preparation of certain indicators and dyes (such as Methyl Orange). The amide of sulfanilic acid is an important drug—perhaps you have heard of it—*sulfanilamide*, the first of the many “Wonder” drugs. If you care to keep your product, carefully dry the crystals, bottle, and label.

The sulfonation of benzene with sulfuric acid produces benzenesulfonic acid. Likewise, phenolsulfonic acid is obtained from phenol. In preparing picric acid (CHEMISTRY, October, 1954), you will recall we first used sulfonation on the phenol and then fol-

lowed through with nitration. The first step in the production of sulfanilamide is the sulfonation of acetanilid with chlorosulfonic acid.

When we think of the remark-

able properties of the sulfa drugs and the hundreds of lives saved through their administration, we can realize the importance of introducing sulfur into organic compounds!

Dutch Pesticide Controls Mites

➤ A NEW, highly effective pesticide that kills injurious plant mites, but leaves beneficial honeybees and other insects alive, has been developed in Dutch laboratories.

In tests the new chemical, Tedion V 18 (short for 2, 4, 5, 4'-tetra-chlorodiphenylsulfone), killed all the eggs and larvae of several harmful mites, though adult mites were unaffected, Dutch researchers H. O. Huisman, R. van der Veen and J. Meltzer reported in the British scientific journal *Nature*.

Tedion V 18 did not show any

visible effects on bees, flies, beetles and other insects, when these were exposed to dried films of the chemical, they said. In addition, large concentrations of the pesticide did not seem to harm plants it was sprayed on.

Large doses of Tedion V 18 given orally to mice did not cause death or any visible symptom of intoxication.

From their tests, the researchers concluded that Tedion V 18 is a highly specific pesticide for mites. It appears to be safe for the sprayer and for the consumer of treated vegetable products.

New Plastic, Methylstyrene

➤ A NEW PLASTIC, methylstyrene, has been introduced as a low-cost, tough material of wide utilization with better resistance to impact and high temperature than its popular plastic cousin, styrene.

The improved plastic molding compound shows no distortion after half an hour in boiling water, James A. Melchore of the American Cyanamid Company's

research division told the American Chemical Society. Like styrene, methylstyrene becomes an even better product when mixed with another plastic material, acrylonitrile.

Like styrene, the new compound can be made clear or in colors and is expected to be used in electronic equipment, signs, toys, textile equipment and aircraft parts.

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